Evaluation of the Effect of Artificial Precipitation Enhancement over Eastern Hexi Corridor*

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ABSTRACT

This paper employed the non-randomization experiments such as the sequential test, the regional control test, the double ratio analysis evaluation method, and the regional regression test to analyze the effects of the artificial precipitation enhancement operations, which were carried out over eastern Hexi Corridor from May to September during 1997-2004. It is discovered that, after the implementation of the artificial precipitation enhancement operations, the rainfall amount increased by 161.5 mm averagely in 8 yr, that is, an average relative precipitation enhancement ratio equals 43%. This indicates that the effects of artificial precipitation enhancement operations over eastern Hexi Corridor are obvious, thus carrying out these operations is feasible. The artificial precipitation enhancement opens a new way for eastern Hexi Corridor to exploit and utilize the air water resources, to ameliorate the ecological environment, and to increase the water store in reservoirs.

Key words: eastern Hexi Corridor, artificial precipitation enhancement (APE), effect evaluation

1. Introduction

Eastern Hexi Corridor lies in the inland arid area, adjacent to the Qilian Mountains in the southeast direction, to the Badain Jaran Desert and the Tengger Desert in the north direction, and to the thousands kilometers of sand drift belt in the northwest direction. The average annual precipitation in this zone is 260 mm, but it is only 110-160 mm in the main agricultural region over the north-central part. The latter is less than one fourth of the national average annual precipitation, thus the water resources in this region is seriously deficient. Furthermore, it is uneven in the spatio-temporal distribution. The agriculture-pasture economic loss due to drought disaster and so on can reach more than 50 million RMB Yuan each year. As EOS/MODIS satellite imagery demonstrated that, the glacier snow line of Qilian Mountains rises at a rate of 2-6.5 m per year, due to the climate warming and drought intensifying since the 1990s. In recent years, the Qilian Mountains glacier-melted-water reduced by about one billion cubic meters compared to that in the 1970s. The glacier in the east part of Qilian Mountains shrinks and the inflow water volume of rivers decreases obviously. The Shiyang River Basin, which is one of the three biggest inland rivers in Gansu Province and flows through Wuwei, Jinchang, Minqin, etc., now in the entire basin occurs the ecological environment unbalance and water resources crisis. Those induced serious ecological environment problems such as the gradual shrinking of forest and meadow vegetations, the ascending of scrub forest lower limit in Qilian Mountains water source self-restraint area, and the decrease of underground water supplement year by year. The confliction between the water resources shortage and the demands from population growth, development of industry and agriculture and every walk of life is more severer. The decreasing of water resources year by year also leads to the ecological environment getting worse, such as the vegetations shrink to a great extent, the numerous xeric plants withering to die, desertification and salinization of soil, the increase of frequency and intensity of duststorm and the aggravation of their harms. Water shortage and drought become the crucial restrictions to industry and agriculture

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development, the ecological environment melioration, and the improvement of the standard of living. It has seriously affected the economic growth and society's sustainable development in the eastern Hexi Corridor region. Therefore, implementing artificial precipitation enhancement (APE) to exploit a new water source becomes a convincing method for developing and utilizing water resources as well as improving the ecological environment.

The research has indicated that there are superior natural conditions for implementing APE in eastern Hexi Corridor region. Although the precipitation in this region is little, the maximum precipitation of the Qilian Mountains located at its south part reaches above 600 mm. It is estimated that the water vapor over the Qilian Mountains has about 15% to be possible to form precipitations. However, only less than 3% of water vapor over the Hexi Corridor forms precipitations and the water vapor transformation efficiency is obviously lower than in other areas in China. This explains that there is a great potential for APE over eastern Hexi Corridor. In the 1990s, some APE experiments had been launched over east section of the Qilian Mountains. The precipitations in the target regions and the downriver beneficial areas increased obviously and as well as the inflow water volume of reservoirs. On the direct-viewing, it seemed to be an ideal working result. Yet there is not a scientific effect evaluation model for the APE operation over arid areas up to now. Therefore, to evaluate the effect of APE objectively, quantitatively, and scientifically will be extremely essential.

2. Current research status

The effect evaluation of weather modification is one of the essential steps in the artificial rain (snow) enhancement operations. On the one hand, the natural precipitation varies greatly in spatial and temporal distribution so that there is a strong instability. On the other hand, nowadays the weather modification mainly through seeding catalysts to influence the natural condensation process within the clouds directly thus the intensity of human influence has a certain limit. Meanwhile, there lacks comprehensive, systematic and thorough understanding of clouds, and the physical mechanism as well as the developing physical process of precipitation, hence it cannot distinguish between the human influence and the natural variation completely. All of these lead the effect examination of weather modification to be an important and extremely difficult scientific problem for both research and operation, in domestic and foreign studies.

At present, the international effect examination (evaluation) methods concluded by Li et al. (2002) are mainly as follows.

(1) The statistician recommends the randomization experiment for it is the most reliable method in science to examine the effect of cloud seeding. On the basis of the natural variability of precipitation and the forecast effect the statistical sample can be computed. In a very low ratio of signal-to-noise, it needs an experiment about 5-10 yr. This is quite a long period and needs plentiful samples. Moreover, the method itself also has difficulty to avoid the influence of a few extreme values and to repel the natural instability of clouds. Moreover, it requests to give up one half of the possible working opportunities. Such many a factor causes the random statistical examination to be unsuitable for being used in actual operations or experiments, so it mainly serves in the research projects.

(2) The non-randomization method delimiting a target region and a control region to examine the effect of cloud seeding, uses many kinds of statistical deducing means synchronously to carry out the statistical analysis on data, and it is an inexpensive, easy way to gain the effect information of cloud seeding for operational activities. It has provided some evidences on the validity of cloud seeding and already been used widely in the world.

(3) With the more thorough research to cloud and precipitation mechanism as well as the developments of probing, numerical simulation and computer technologies, we can reduce the restriction of natural precipitation variability through the exploration of physics predictors, and provide the new comprehensive effect examination combined with the ensemble data statistical method, physical method, numerical simulation and so on, all of which open the developing

prospect of effect evaluations from various aspects.

The weather modification operations develop rapidly in China, thus there is an urgent demand to use effect evaluation methods of weather modification suitably for the national situation and the local conditions. Experiments carried out in many places put forward the experiment reports concerning the non-randomization statistical experiment, the statistical examination, the physical examination, and their integration. Hu (1979) appraised the application of numerical simulation in weather modification operation design, effect evaluation and so on. Zeng et al. (1991) and Zeng (1998) analyzed various non-randomization effect evaluation methods adopted in the APE operations over Gutian County of Fujian Province.

3. Basic situations of the operations

The APE operation over eastern Hexi Corridor started in 1992. The locations and beginning years of the working spots can be seen in Table 1. The way is seeding AgI preparation with 37 mm antiaircraft artilleries or rocket into the clouds to increase the condensation nucleus within the clouds. The period for APE operations is from May to September during flood season; the precipitation cloud exertting artificial influence is the large scale stratus system or the cumulonimbus that develops strongly in local area. We selected 65 samples within the period of May to September during 1997-2004 in Yongchang County of Jinchang City. After the executions of APE operations, the average rainfall amount is 11.9 mm and the maximum is 39.9 mm. We also selected 71 samples during the coinstantaneous period in Liangzhou District of Wuwei City. After the APE operations, the average rainfall amount is 9.3 mm and the maximum rainfall amount is 26.3 mm.

Table 1. Basic information of the APE operations

County(District)	Number of working spots	Beginning year of operations
Liangzhou	3	1995
Yongchang	8	1992
Gulang	5	2001
Tianzhu	3	2001
Minqin	4	2003

4. Effect evaluation methods

4.1 *The confirmation of effect evaluation methods*

The artificial rain (snow) enhancement operation serves as a way to fight against droughts. In the position of effect examination, it belongs to one kind of non-randomization experiment and can be tested by some recognized feasible methods (Ye and Fan, 1982; Department of Scientific and Technological Development of CMA, 2003; Zhang, 1992). During the 1980s, the research projects on APE of stratus over northern China made some fruitful progresses. These research results, fitting with the current knowledge level and the equipment condition, have shown great experiences in collocating target regions, choosing the catalyzed object as well as controlling the seeding plan, dosage, etc., and make every effort to enable each operation to enhance the rainfall. This is the essential goal of rain enhancement operation for drought mitigation, and it is also the prerequisite of the effect evaluation. This paper uses such methods as the sequential test, the regional target/control test, the double ratio analysis evaluation method, and the regional historical regression test.

4.2 *The confirmation of target/control region*

The APE for drought mitigation implemented in arid areas is a kind of experiment which is carried out under a situation consisting of multitudinous uncertain factors, and its consequence is difficult to predict. Therefore, not only the working plan and the catalysis technology must conform to the scientific principle, but also the working effect evaluation should have scientific characters and particularly needs to appraise the working effect objectively. The existing non-randomization experiments with the statistical evaluation methods all use the certain control variables to estimate natural rainfall in target region under the certain supposition premises, and then compare it with actual rainfall in target region to appraise the working effect. Regarding the systematic precipitation process, we can use the regional control tendency analysis method to appraise the working effect, namely choosing a neighboring contrast region with a similar cloud system structure to the operation region.

To determine the control region and the target region, the following basic principles should be satisfied: (1) the basic climate-indices are comparable; (2) the precipitation systems and the main cloud systems occurring in two regions are similar; (3) the geographical characteristics are similar; (4) the regional areas are similar; (5) the control region cannot be polluted by catalyst used in target region; (6) the stations within two regions are representative and distributed evenly; and (7) the data are taken almost synchronously.

According to the above mentioned basic principles, we selected Yongchang County of Jinchang City as target region 1, and selected the Liangzhou District of Wuwei City as target region 2. The selected control region is located at NE direction or N direction of the target regions (windward direction, the 500 hPa wind direction is NW), that is, Minqin County which adjoins to Liangzhou District and Yongchang County (not influenced by catalyst that was used in target regions). The distance between Liangzhou and Minqin is 91 km, and 107 km between Yongchang and Minqin (see Fig.1). The basic status of target regions and the control region can be seen in Table 2, and they mainly satisfy the above basic principles.

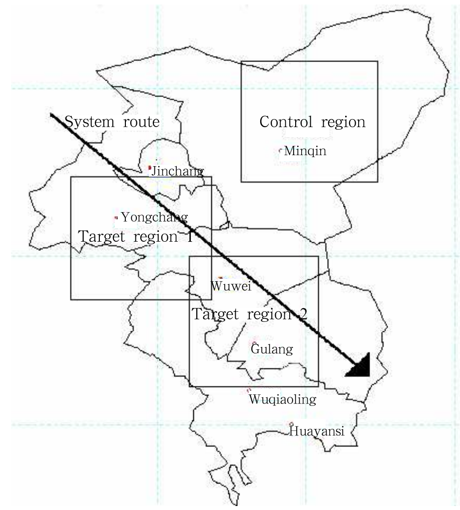

Fig.1. The target regions 1 and 2 and control region for APE operations.

Table 2. The basic status of target regions and the control region

Region type	Place name	Area (10^3km^2)	Altitude (km)	Annual precipitation (mm)	Climatic characters
Target region 1	Liangzhou District	6.2	1.53	165.9	Temperate zone, arid
Target region 2	Yongchang County	7.4	1.98	201.7	Temperate zone, arid
Control region	Minqin County	16	1.67	113.4	Temperate zone, desert

4.3 *The selection of effect evaluation period and data*

This paper selects a period of 1997-2004 during which the APE operations are carried out in Yongchang County and Liangzhou District, and the working months are from May to September. The historical data include the precipitation records at Wuwei, Yongchang, and Minqin Stations during 1967-1996. The data of target regions are selected from the precipitation records after APE implements during 1997-2003; the data of control region corresponding to no APE processes in Minqin are 136 times in total.

5. The effect evaluations

5.1 *The sequential test*

5.1.1 *Counting the increase of precipitation*

The sequential test uses the historical average precipitation over a target region as the natural precipitation estimating value, then compares it with the actual precipitation during experimental time, thus obtains the effect value of the human influence. Here set the actual gauge precipitation of each APE month within experimental time during 1997-2004 to a matrix $\boldsymbol{X}_{1i}$; set historical average monthly precipitations of 30 yr (1967-1996) over target regions to $\boldsymbol{X}_{2i}$, and serve as the precipitation estimating values of experimental time. Because the period of historical samples is quite long, we can regard the natural precipitation over target regions as steady distribution to the time. According to the following formula

$$\Delta R = \Sigma(\boldsymbol{X}_{1i} - \boldsymbol{X}_{2i}), \qquad E = \Sigma(\boldsymbol{X}_{1i} - \boldsymbol{X}_{2i})/\Sigma \boldsymbol{X}_{2i},$$

we can calculate the absolute increment ΔR and the relative value E of the effect corresponding to the working time. The monthly mean absolute increase of precipitation in Yongchang is 16.0 mm and the mean relative value is 53.3%; the monthly mean absolute increase of precipitation in Liangzhou is 13.8 mm and the mean relative value is 53.2% (see Table 3).

5.1.2 *Testing the significant level of effect*

Suppose H_0: $\Sigma \boldsymbol{X}_{1i} = \Sigma \boldsymbol{X}_{2i}$, namely there is no significant difference of precipitation between before and after APE operation.

Here n=21 indicates the number of months in which APE are carried out over Yongchang County; among them n^+=18 indicates there are 18 months with positive effect for APE and n^-=3 is the number of months with negative effect; r=min(n^+, n^-)=3. To Liangzhou Dirstrict, three values are n=22, n^+=19, and n^-=3, respectively; r =min(n^+, n^-)=3, too. According to the statistics theory, when n is big enough, it can be treated as such a normal distribution $N(n/2, (\pi/4)^{1/2})$, approximately.

Using the t-test, the statistical variable

$$t = (r - n/2)/(\pi/4)^{1/2}.$$

The computational results are $t_{\rm YC}$=-6.77, $t_{\rm LZ}$= -7.34; when α=0.01, t_α confidence interval is (-2.58, 2.58). Due to $t_{\rm YC}< t_\alpha$ and $t_{\rm LZ}< t_\alpha$, here rejects the original hypothesis. These indicate that the precipitations in the two target regions after APEs are obviously higher than the relevant natural precipitations, with significant levels less than 0.01 (see Table 3).

Table 3. Parameters of the sequential test over target regions

Place name	Months for APE (n)	Months with positive effect (n^+)	Months with negative effect (n^-)	Min(n^+, n^-) (r)	Total historical precipitation ($\Sigma \boldsymbol{X}_2$)	Actual precipitation in total ($\Sigma \boldsymbol{X}_1$)
Yongchang	21	18	3	3	622.2	968.2
Liangzhou	22	19	3	3	572.8	877.3
Place name	**Absolute increment of precipitation (ΔR)**	**Relative increment of precipitation (E)**	**Significant level (α)**	**Critical value for t-test (t_α)**	**Computational value (t)**	
Yongchang	16.0	53.3%	0.01	-2.58	-6.77	
Liangzhou	13.8	53.2%	0.01	-2.58	-7.34	

5.2 *The regional target/control test*

5.2.1 *Counting the increase of precipitation*

The regional target/control test uses the rainfall in the corresponding period over the control region as the estimating value of natural rainfall over target region; then comparing this value with the actual precipitation over target region after the implementation of APE to obtain the catalyzed effect. Taking the target region 1 (A1) as Yongchang County, the target region 2 (A2) as Liangzhou District and the control region (B) as Minqin County. Because both Yongchang and Liangzhou adjoin to Minqin, the spatial distribution of natural precipitations over target regions can be regarded as steady. It can be calculated that the minimum effect of APE in Yongchang is 18% and 28% in Liangzhou (table omitted).

5.2.2 *Testing the significant level of effect*

Suppose H_0: A=B, namely there is no significant difference of precipitation between before and after APE operations.

Here n=45 indicates the number of months in which APEs are carried out over Yongchang County; among them n^+=37 indicates there are 37 months with positive effect for precipitation enhancements and n^-=8 is the number of months with negative effect; r=min(n^+, n^-)=8. To Liangzhou, three values are n=52, n^+=47, and n^-=5, respectively; r=min(n^+, n^-)=5. According to the statistics theory, when n is big enough, it can be treated as such a normal distribution $N(n/2, (\pi/4)^{1/2})$, approximately.

Using the t-test, the statistical variable

$$t = (r - n/2)/(\pi/4)^{1/2}.$$

Calculating t values of the two target regions, we get $t_{\rm YC}$=-11.85, $t_{\rm LZ}$=-20.88; when α=0.01, t_α confidence interval is (-2.58, 2.58). Due to $t_{\rm YC}<t_\alpha$, and $t_{\rm LZ}<t_\alpha$ here rejects the original hypothesis. These indicate that the precipitation in two target regions after APE operations are obviously higher than the relevant natural precipitations, with significant levels less than 0.01 (see Table 4).

Table 4. Parameters of the regional target/control test over target regions

Place name	Months for APE (n)	Months with positive effect (n^+)	Months with negative effect (n^-)	Min(n^+, n^-) (r)	Minimum APE ratio (p)	Significant level (α)	Critical value for t-test (t_α)	t value
Yongchang	45	37	8	8	18%	0.01	-2.58	-11.85
Liangzhou	52	47	5	5	28%	0.01	-2.58	-20.88

5.3 *The regional regression test*

5.3.1 *Counting the precipitation increment of the double ratio analysis evaluation method*

The double ratio analysis evaluation method is based on the ratio of the mean rainfall value y_2 over a target region within the catalyzed population to the actual mean rainfall value x_2 over the control region and then comparing this ratio with another ratio of the mean rainfall y_1 over a target region within the non-catalyzed population to the average natural rainfall x_1 over the control region.

Make $R = (y_2/x_2)/(y_1/x_1)$.

Here the ratio $R \leqslant 1$ indicates the negative effect, $R>1$ indicates the positive effect and the ratio of APE is $E = R$-1.

In the processes of the double ratio analysis evaluation method, using the historical data from May to September during 1967-1996 in the target region 1(Yongchang), the target region 2 (Liangzhou), and the control region (Minqin) to calculate the average rainfall y_1 or x_1 in each month respectively. Using the APE data from May to September during 1997-2003 in Yongchang, Liangzhou, and Minqin (the APE over Minqin launched in 2003) to calculate the rainfall after APE labeled y_2 or x_2 in each month respectively. Finally, according to $R = (y_2/x_2)/(y_1/x_1)$ one can calculate that the APE effects of Yongchang and Liangzhou are 47.9% and 47.4%, respectively. These analysis results can be seen in Table 5.

5.3.2 *Counting the precipitation increment of regional historical regression test*

The regional historical regression test uses the natural rainfall over the control region as a forecast (control variable), then makes statistical conclusion on the natural rainfall over target regions. It is based on one or more control regions, establishing the natural precipitation regression equation between target regions and control regions according to the historical

Table 5. Double-comparison analysis on the APE effect of the regional mean rainfalls

		Non-catalyzed	Catalyzed
	Sample size	150	35
Yongchang	y	32.9	48.4
Liangzhou	y	27.2	39.9
Minqin	x	19.4	19.3
Yongchang	y/x	1.696	2.508
Liangzhou	y/x	1.402	2.067
Yongchang	R		1.479
Liangzhou	R		1.474

data; and estimating the natural precipitation over target regions by the natural precipitation over control regions during the experimental time, based on the above regression equation. In the process of regional regression, it uses the historical data from May to September during 1967-1996 in the target region 1 (Yongchang), the target region 2 (Liangzhou), and the control region (Minqin) to analyze the rainfall data in each month respectively, and to establish the regional historical regression equation for computing the effect of APE. After the experiment, the correlation coefficients of historical average monthly rainfall between target region 1 and control region or between target region 2 and control region are both above 0.51, and the significant levels both above 0.05; the significant level, of the equation is also above 0.05. Table 6 shows the main parameters of regional precipitation historical regression in each month. Among them, $\overline{x}$ is the multi-year mean value of monthly precipitation over the control region; $\overline{y}$ is the multi-year mean value of monthly precipitation over the target regions; s_x is the standard deviation of monthly precipitation over the control region; s_y is the standard deviation of monthly precipitation over the target regions; and r is the correlation coefficient between control region and target regions. Table 6 also shows the regional historical regression equations in each month, the absolute rainfall increments and the ratios of average relative rainfall

Table 6. Analysis on the main parameters of the regional historical regression test

Month		$\overline{x}$	$\overline{y}$	s_x	s_y	r	Regression equation	Rainfall increment	Average rainfall increment ratio
May	Yongchang	10.3	19.5	9.7	14.6	0.76	y=0.115x+7.05	30.6	41.3%
	Liangzhou	9.2	16.1	9.1	10.9	0.79	y=0.095x+6.14	10.6	55.0%
Jun.	Yongchang	15.6	35.2	12.5	24.0	0.84	y=0.160x+9.65	14.3	27.1%
	Liangzhou	16.0	26.8	14.9	18.9	0.54	y=0.069x+12.79	33.1	37.8%
Jul.	Yongchang	20.4	37.3	16.0	18.1	0.55	y=0.051x+25.89	121.0	69.3%
	Liangzhou	24.6	29.7	16.7	13.7	0.58	y=0.048x+17.21	36.1	67.2%
Aug.	Yongchang	31.6	41.0	21.6	22.1	0.51	y=0.042x+27.25		No APE during summer harvest period
	Liangzhou	29.7	39.1	21.2	27.4	0.57	y=0.074x+15.04	29.1	26.3%
Sep.	Yongchang	16.8	31.6	12.7	22.8	0.63	y=0.113x+12.73	23.0	18.8%
	Liangzhou	17.5	24.4	12.1	17.3	0.70	y=0.101x+8.09	25.1	49.6%

Table 7. The significance examinations on the main parameters of the regional historical regression test

Month		Examination on regression coefficient (T)	Significant level (α)	Examination on equation significance (F)	Significant level (α)
May	Yongchang	3.99	0.001	38.91	0.01
	Liangzhou	4.15	0.001	47.50	0.01
Jun.	Yongchang	4.36	0.001	64.55	0.01
	Liangzhou	2.84	0.01	11.50	0.01
Jul.	Yongchang	2.38	0.05	6.15	0.05
	Liangzhou	3.06	0.01	14.35	0.01
Aug.	Yongchang	2.16	0.05	5.67	0.05
	Liangzhou	3.00	0.01	13.49	0.01
Sep.	Yongchang	3.32	0.01	18.62	0.01
	Liangzhou	3.63	0.01	27.30	0.01

increments. Table 7 shows the main significant examination parameters in each month of the regional historical regression test.

When employing statistical analysis on the regional historical regression equation, we eliminated those months whether APE operation was carried out or neither in the control region nor in the target regions at the same time. As a result of the analysis on APE, during 1997-2003, the absolute rainfall increments of Yongchang and Liangzhou in May are 30.6 and 10.6 mm, respectively; the average relative rainfall increment ratios are 41.3% and 55.0%, respectively. The absolute rainfall increments in June are 14.3 and 33.1 mm, respectively; the average relative rainfall increment ratios are 27.1% and 37.8%, respectively. The absolute rainfall increments in July are 121.0 and 36.1 mm, respectively; the average relative rainfall increment ratios are 69.3% and 67.2%, respectively. The absolute rainfall increments in September are 23.0 mm and 25.1 mm, respectively; the average relative rainfall increment ratios are 18.8% and 49.6%, respectively. In August, the absolute rainfall increment of Liangzhou is 29.1 mm and the average relative rainfall increment ratio is 26.3%, and it is just the summer harvest time of Yongchang so there is no APE operation being carried out. The average relative effects of APE in Yongchang and Liangzhou are up to 39% and 47%, respectively.

It is not difficult to see from Table 6 that the effects of APE are more remarkable in those months with more precipitation frequencies and longer duration of precipitations themselves, during the APE period from May to September. For instance, the effects of APE in Yongchang and Liangzhou are 69.3% and 67.2% in July, which involve more suitable processes for APE, more sufficient water vapor content in the cloud system, and more thorough catalysis of AgI. According to the analysis on the monthly APE ratios and the average APE ratios of Yongchang and Liangzhou, Liangzhou lies in the leeward direction of Yongchang, and it is not only influenced by the catalysis effect within local area but also by the catalysis effect in the upstream area. Therefore its APE effect surpasses that of Yongchang obviously.

5.3.3 *Testing the significant levels of effects*

Suppose H_0: $X = Y$, namely there is no remarkable rainfall amount difference between the non-catalyzed unit and the catalyzed unit.

Using the rank-sum u-test to examine the significances of the APE effects and the sample is all rainfall samples of the non-catalyzed unit and the catalyzed unit during the APE season from May to September 1997-2003. $X_{\rm ns}$ and $X_{\rm s}$ are the rainfall amounts of the non-catalyzed unit and the catalyzed unit (target regions), respectively. The sample size with APE operations in target region 1 (Yongchang) is n_1=82 and without APE operations is n_2=103; the sample size with APE operations in target region 2 (Liangzhou) is n_1=65 and without APE activities is n_2=82. The rank sequence table is omitted, the rank-sum and T_{n1} are equal to 10864 and 7078, respectively. Compute the statistical variable U by use of

$$U = (T - n_1(n_1 + n_2 + 1)/2)/(n_1 n_2(n_1 + n_2 + 1)/12)^{1/2}.$$

The computational results are $U_{\rm YC}$=3.55, $U_{\rm LZ}$=2.98. When α=0.01, the confidence interval of u_α is (-2.58, 2.58). For $U_{\rm YC} > u_\alpha$ in target region 1 and $U_{\rm LZ} > u_\alpha$ in target region 2, then it rejects the original hypothesis. This indicates that the rainfall amount in a target region of non-catalyzed unit is obviously smaller than the rainfall amount in a target region of catalyzed unit, and the significant level is smaller than 0.01 as well (see Table 8).

Table 8. The examination parameters of the regional regression test for examining the effect of APE

	Sample of non-catalyzed unit (n_1)	Sample of catalyzed unit (n_2)	Significant level (α)	Test critical value (u_α)	Computational value (u)
Yongchang	103	82	0.01	2.58	3.55
Liangzhou	84	65	0.01	2.58	2.98

5.4 *The statistical scheme comparison of test effects*

It can be seen from the above tests that the regional target/control test, the sequential test, the double ratio analysis evaluation method, and the regional historical regression test all proved that there are significant effects of APE which is carried out over eastern Hexi Corridor. But as a result of the natural precipitation fluctuation, it may produce false effects of APE. Then, which test can assess the APE effects more objectively and accurately? It was proved by many non-randomization experiments on APE (Zeng, 1997; Li et al., 2000; Yang et al., 2004). The sequential test, the regional target/control test, and the double ratio analysis evaluation method have lower sensitivities and greater distortion ratios, which may cause the greater false effects and have lower efficiencies. The regional historical regression test has a higher sensitivity, a smaller distortion ratio, the fewest false effects among all tests and the highest efficiency due to a great deal of sample size. Therefore, the scheme of the regional historical regression test can reflect the actual situation of APE more objectively and accurately, and can meet the requirement of the effect evaluation about APE. Thus it is known that, in APE season from May to September during 1997-2003, the accumulated absolute rainfall increments of the APE experiments implemented over Yongchang and Liangzhou are 188.9 and 134 mm, respectively; the average relative rainfall increment ratios are 39% and 47%, respectively. The mean relative rainfall increment ratio between the two regions is equal to 43%.

6. Conclusions and discussions

(1) The experiments on the sequential test, the regional target/control test, the regional double ratio analysis evaluation method, and the regional historical regression test method all proved that the APE operations have remarkable effects qualitatively. The significant levels of test results all surpass 0.05, and namely the confidence levels are all above 95%.

(2) Among the effect evaluation methods, the regional regression test analyzes the effect of APE more objectively and accurately. The quantitative effects of APE operations in Yongchang and Liangzhou are 39% and 47%, respectively. The average APE effect of the

two regions equals 43%.

(3) According to the effect analysis on APE, the rainfall increment ratio in Liangzhou is obviously higher than in Yongchang, indicating that Liangzhou is not only influenced by the catalysis effect within local area but also by the second catalysis effect in the upstream area. This fully proved that the catalyzed area of an APE spot is limited. If we set up more APE spots in a definite area to carry out APE operations synchronously and carry out associated operations between the different regions, the catalysis will be more thorough as well as the effects of APE will be more remarkable.

(4) Among the large scale APE plans which established one after another in worldwide, e.g., the Climax I-II winter terrain-cloud ground seeding AgI-smoke experiment, the FACE I - II cumulus dynamic catalyzing plan, the HIPLEX- I (cumulus catalyzing experiment), the Cascade winter storm influencing plan, the COSE winter terrain-cloud influencing plan, the SCPP terrain-cloud influencing plan, etc., those developed in United States, obtained an average snow increment ratio of 10%-15% by statistical analysis; other national rainfall enhancement plan such as the Israel I-III cumulus rainfall enhancement experiment, the Syrian convective cloud and frontal cloud artificial rainfall enhancement plan, the Japanese weather modification plan, the Australian rainfall enhancement plan, etc., all have a rainfall increment ratio about 15%; In China, the randomization experiments on APE carried out in Gutian County of Fujian Province, obtained a rainfall increment ratio of 20%-24% (Zhang, 1998). Otherwise, the APE experiments carried out over eastern Hexi Corridor, obtained an average rainfall increment ratio up to 43%. This indicates that there is a great exploitable air water resource over eastern Hexi Corridor, the effects of APE experiment over this region is obvious, and to develop APE operations over this region is feasible. The APE operation opens a new way to exploit and utilize the water resources, to meliorate the ecological environment, and to increase the water storage in reservoirs for eastern Hexi Corridor.

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